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POSITIVE RAY ANALYSIS OF IONS FROM A HIGH FREQUENCY SPARK

A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE PHYS-
ICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICS

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Positive Ray Analysis of Ions from a High Frequency Spark

SHENG-LIN CH'U, *Ryerson Physical Laboratory, University of Chicago*

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This paper gives the analysis by the Thomson parabola method of the positive rays of various materials produced by the high frequency spark method developed by Dempster. The spark materials investigated may be classified into three groups, i.e., metals of high melting point, metals of low melting point and minerals. It was found that almost all the ions obtained were atomic and that most of the elements gave multiply charged ions. The change of charges during the passage from

the accelerating field to the analyzing field was also observed. Ions of the elements which exist ordinarily in the gaseous state were obtained from the solid compounds of which these elements form constituents. Helium ions were obtained from the radioactive mineral, cleveite ($\text{UO}_2 \cdot \text{UO}_3 \cdot \text{PO} \cdot \text{ThO}_2$). From the experiments thus far performed, the high frequency spark method has been shown to be able to give strong sources of multiply charged ions of almost all the elements.

IN a previous paper A. J. Dempster¹ has discussed various forms of spark sources for positive ions, and pointed out the possibility of obtaining charged ions from a high frequency oscillatory discharge between metal electrodes in a high vacuum. This paper forms an extension of those experiments and gives the analysis by the Thomson parabola method of the ions formed by sparks between electrodes of a great many elements.

The mounting of the spark electrodes is shown in Fig. 1. The two electrodes are held in position by means of two sylphon bellows and three screws attached to each of the bellows between *AB* and *BC* so that by adjusting the screws the upper electrode can be moved with respect to the lower one, and in addition the whole spark gap moved with respect to the circular aperture *S*₁. The lower electrode is attached to the metallic part of the spark chamber and the upper one is insulated by means of a thick wall glass tube. The two metallic disks between which the ions are accelerated are held parallel by three alsmag insulators kindly supplied by the American Lava Company, so that the apertures *S*₁, *S*₂ and *S*₃ (Fig. 1) once adjusted will remain in a straight line throughout the experiments. These two disks forming a unit are screwed onto the cylindrical chamber and can be detached for changing the electrodes. The whole spark chamber is mounted on the analyzing chamber by three threaded rods of linen Bakelite between *C* and *D*. The glass tube forming the wall of the vacuum space is waxed to the metal part with picein wax.

A large side tube is connected for exhausting. Holes are also made in the metal cylinder inside the glass tube to facilitate the evacuation and serve as windows through which the spark may be observed. The Tesla circuit is arranged in a compact form and immersed in a five-gallon earthenware jar filled with oil.

The analyzing chamber with the spark chamber attached is shown in Fig. 1. The chamber is a brass casting, and the axis of the spark chamber and the collimating system is inclined at an angle such that the direct beam hits close to the upper edge of the photographic plate. The aperture *S*₃ at the end of the collimating tube has a diameter of 0.1 mm. The other two, *S*₁ and *S*₂ mentioned before, are of $\frac{1}{2}$ and $\frac{1}{4}$ mm diameter respectively. The analyzing fields lie just beyond the aperture *S*₃. The magnetic pole pieces are fastened on a brass frame which is made to fit inside the chamber. The upper and lower brass walls of the chamber in contact with the pole pieces are cut out and iron pieces inserted so that an electromagnet can be placed outside the chamber. The negative terminal of the deflecting potential is connected to a thin brass plate which is attached to the lower magnetic pole, and insulated by a piece of amber; the upper magnetic pole piece which has metallic contact with the wall of the chamber serves at the same time as the positive electric plate. It was found necessary to shield the battery and the leads in order to avoid fluctuation of potential while the oscillating circuit is functioning. The photographic plate holder was each time waxed onto the chamber with picein wax. A wide tube shown in the

¹ A. J. Dempster, *Rev. Sci. Inst.* **7**, 46 (1936).

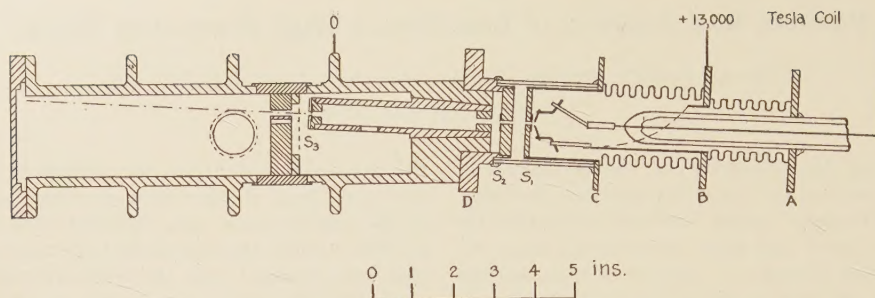


FIG. 1. Apparatus for the analysis of ions from a spark source by the parabola method.

diagram by a circle serves to evacuate the chamber.

A constant accelerating potential applied across the gap between S_1 and S_2 is obtained from a rectifier (FP-85) together with a large capacity condenser and a choke. The average current through the spark as measured by a thermocouple ammeter was between 0.1 and 0.25 ampere.

The materials thus far investigated may be classified into three groups, namely, (1) metals of high melting point, (2) metals of low melting point, below 1000°C , and (3) minerals. With the materials of the first group, electrodes were prepared by cutting a short rod of the metal, about 5 or 6 mm long and 1 mm in diameter. The materials of the second group were put in nickel tubes of about 1 mm diameter, which were then fixed into the electrodes in the same way as the metal rods of the first group. Some soft metals such as lithium and barium were simply pressed into the nickel tube. Some, such as tin and lead, were melted in the tube by heating. The titanium metal is very brittle, so that it is difficult to cut out a thin rod. Also because of its reaction with any metal upon heating, a thick wall nickel tube was used and filled with powdered metal. Minerals were usually ground into powder and then put into the nickel tube. The nickel tubes filled with the material were used only as the lower electrode, the upper one being simply a nickel rod.

The pressure under which the spark was produced was about 10^{-5} mm. With an accelerating potential of about 13 kv, positive ray pictures were obtained by an exposure of two to three minutes with Schumann plates. Examples are given in Fig. 2.

With this arrangement of apparatus, ions were all produced in the spark region where the electric field was low, due to the intense ionization in the spark, and were then accelerated across a constant high potential of 13 kv. Ions of the same value of e and m would therefore have the same energy when entering the analyzing fields and would have the same deflections. Thus the patterns obtained consist of discrete spots instead of continuous parabolas. Analysis of the pattern can be made by means of the general consideration given below.

It was originally shown by J. J. Thomson² that deflections of the path of ions passing through electric and magnetic fields perpendicular to the direction of motion are given respectively by $x = AeE/mv^2$ (1), and $y = BeH/mv$ (2), where A and B are constants. Eliminating v from (1) and (2), one gets $y^2 = (B^2H^2/AE)(e/m)x$ (3), showing that particles of the same value of e/m but different v lie on the same parabola. As the particle may be multiply charged, one may put $e = ne_0$ where e_0 is the electronic charge. Now if we consider a particle having a charge ne_0 during acceleration and $n'e_0$ during deflection, (1) and (2) become $x = A(n'e_0/m)(E/v^2)$ (4) and $y = B(n'e_0/m)(H/v)$ (5). Also $\frac{1}{2}mv^2 = Vne_0$ (6). Substituting the v from (6) into (4) and (5), one gets $x = A(E/2V)(n'/n)$ (7) and $y = BH(e_0/2V) \times (n'/nm)$ (8). From (8) and (9), when n is eliminated, $y^2 = (B^2H^2/AE)(n'e_0/m)x$, and when n' is eliminated, $y = (BH/AE)(2Ve_0/nm)x$. Therefore for a given mass m , spots of the same n' but of different n lie on a parabola and spots of same n but of different n' lie on a straight line passing through the origin. A theoretical pattern for a constant m is shown in Fig. 3.

² J. J. Thomson, *Rays of Positive Electricity*, 2nd ed., pp. 16-21.

Now in general a particle may retain its charge or lose it partly or completely by capturing electrons during its passage from the accelerating gap to the deflecting fields. The converse phenomenon, that is an increase of charge, was not observed.

For different values of m , the same pattern will be repeated with only a shift of y value, x will be the same for all values of m as shown by (7).

Along the line A (Fig. 3), $n=n'$ for each point, then (7) and (8) become $x=AE/2V=\text{constant}$, and $y=BH(e_0/2V)(n/m)$, or $y^2m/n=K$ (9). Thus by measuring the y distance along the line A and taking into consideration the fact that points of low value of n or n' always appear strong, one can easily identify the elements corresponding to points on the photographic plates and assign the proper number of charges.

Almost all the ions were atomic except that sometimes a weak trace of the hydrogen molecule ion appeared. Isotopes of light elements such as lithium and boron were clearly resolved.

Most of the elements gave multiply charged ions. Hydrogen, lithium, sodium and potassium had only singly charged ions, beryllium and barium were singly and doubly charged, boron and aluminum singly, doubly and triply charged and carbon with all charges up to four. These phenomena agree with other experiments in showing the existence of the easily ionized valence electrons in atoms. But elements which possess more than four valence electrons did not give higher multiplicity of charge. This is perhaps due to the comparatively high ionization potential of the remaining electrons.

The materials examined are listed below. The various charged ions found are given, followed by the changes of charge observed, the figures in brackets (nn') indicate an ion of n' charges, with the energy of an ion originally accelerated with n charges.

Iron treated with hydrogen $\text{Fe}^+ \text{Fe}^{++} \text{Fe}^{+++} \text{H}^+ \text{H}_2^+ \text{O}^+ \text{O}^{++}$
 $\text{C}^+ \text{C}^{++} \text{C}^{+++} \text{Fe} (31)(21)(32)$

Steel $\text{Fe}^+ \text{Fe}^{++} \text{Fe}^{+++} \text{C}^+ \text{C}^{++} \text{C}^{+++} \text{O}^+ \text{O}^{++} \text{N}^+ \text{Fe} (41)(31)$
 $(21)(42)(32)(43)$

Cu and Al Alloy $\text{Cu}^+ \text{Cu}^{++} \text{Cu}^{+++} \text{Al}^+ \text{Al}^{++} \text{Al}^{+++} \text{O}^+ \text{C}^+$
 $\text{Cu and Al} (31)(21)(32)$

Speculum metal $\text{Cu}^+ \text{Cu}^{++} \text{Cu}^{+++} \text{Cu}^{++++} \text{Sn}^+ \text{Sn}^{++} \text{Sn}^{+++}$
 $\text{Sn}^{++++} \text{O}^+ \text{C}^+ \text{N}^+ \text{Cu and Sn} (41)(31)(21)(42)(32)(43)$

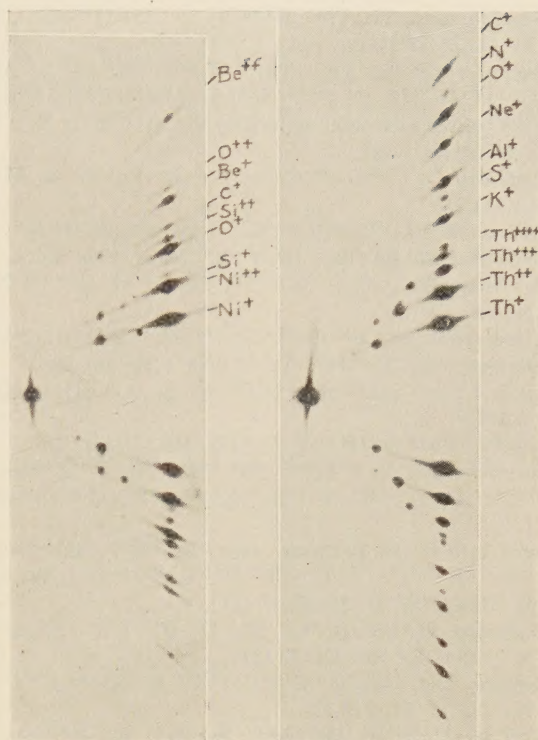


FIG. 2. (a) Ions from beryl, (b) ions from thorium.

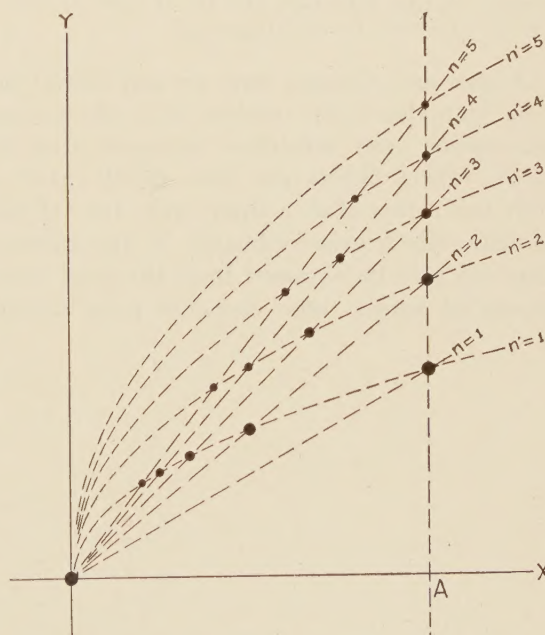


FIG. 3. Diagram of the spots on the various parabolae due to ions analyzed with n' charges, when they were originally accelerated as ions having n charges.

Titanium metal Ti^+ Ti^{++} Ti^{+++} Ti^{++++} O^+ O^{++} C^+ C^{++}
 Ti (41)(31)(21)(32)
Thorium metal Th^+ Th^{++} Th^{+++} Th^{++++} K^+ Cl^+ S^+ Al^+
 O^+ O^{++} N^+ N^{++} C^+ C^{++} $^{20}\text{Ne}^+$? Th (31)(21)(42)(32)(43)
Nickel (tested with other materials) Ni^+ Ni^{++} Ni^{+++} Ni^{++++}
 Ni (31)(21)(32)
Pencil core C^+ C^{++} C^{+++} C^{++++} Na^+ K^+ Fe^+ Si^+ or Al^+ ?
 C (31)(21)
Lithium metal $^6\text{Li}^+$ $^7\text{Li}^+$ ($^6\text{Li}^{++}$ $^7\text{Li}^{++}$) (very weak) O^+ N^+ C^+
Beryllium metal Be^+ Be^{++} O^+ O^{++} C^+ N^+ N^{++} H_2^+ Be (21)
Barium metal Ba^+ Ba^{++} Ba^{+++} Ti^+ Y^+ Sc^+ O^+ O^{++} C^+ N^+
 N^{++} Ba (31)(21)
Cerium metal Ce^+ Ce^{++} Ce^{+++} H^+ H_2^+ H_3^+ Ce (31)(21)(32)
Tellurium metal Te^+ Te^{++} Te^{+++} $^{21}\text{Ne}^+$? Te (31)(21)
Tin Sn^+ Sn^{++} Sn^{+++} Sn^{++++} O^+ C^+ Sn (41)(31)(21)(42)
 (32)(43)
Lead Pb^+ Pb^{++} O^+ O^{++} C^+ C^{++} Pb (31)(21)(32)
Ferro-boron Fe^+ Fe^{++} Fe^{+++} $^{10}\text{B}^+$ $^{10}\text{B}^{++}$ $^{10}\text{B}^{+++}$ $^{11}\text{B}^+$ $^{11}\text{B}^{++}$
 $^{11}\text{B}^{+++}$ O^+ O^{++} N^+ N^{++} Na^+ K^+ Fe (31)(21)(32)B (31)
 (21)
Boron carbide and Uranium oxide $^{10}\text{B}^+$ $^{10}\text{B}^{++}$ $^{10}\text{B}^{+++}$ $^{11}\text{B}^+$
 $^{11}\text{B}^{++}$ $^{11}\text{B}^{+++}$ C^+ C^{++} C^{+++} U^+ U^{++} U^{+++} O^+ O^{++} Na^+ K^+
 B (31)(21)(32) U (21)(32) O (21)
Spodumene $\text{LiAl}(\text{SiO}_3)_2$ $^6\text{Li}^+$ $^7\text{Li}^+$ O^+ O^{++} O^{+++} Si^+ Si^{++}
 Si^{+++} Na^+ K^+ Rb^+ Cs^+ Si (21)
Uranium oxide U_3O_8 U^+ U^{++} U^{+++} O^+ O^{++} O^{+++} C^+ C^{++}
 Na^+ K^+ U (31)(21)(32)
Beryl $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ Be^+ Be^{++} Si^+ Si^{++} O^+ O^{++} O^{+++}
 N^+ N^{++} C^+ C^{++} Be (21) Si (31)(21)(32)
Goethite $\text{FeO}(\text{OH})$ H^+ H_2^+ Fe^+ Fe^{++} Fe^{+++} O^+ O^{++} O^{+++}
 C^+ C^{++} Fe (31)(21)(32)
Manganite $\text{MnO}(\text{OH})$ H^+ H_2^+ O^+ O^{++} C^+ Mn^+ ? (not
 observed)
Cleveite $\text{UO}_2 \cdot \text{UO}_3 \cdot \text{PbO} \cdot \text{ThO}_2$ He^+ H^+ H_2^+ O^+ O^{++} O^{+++}
 U^+ U^{++} U^{+++} C^+ C^{++} U (31)(21)(32).

Oxygen and nitrogen were present almost on every plate due to the residual air in the system and carbon also sometime appeared due to grease vapors. These gas ions usually gave a short line rather than a sharp spot. Ions of the elements which exist ordinarily in the gaseous state can also be obtained from the solid compounds of which those elements form consti-

tuents. Thus some of the minerals tested were compounds containing hydrogen and oxygen, often oxides with water of crystallization. Ions of the latter two elements were strongly shown on the plates.

Hydrogen ions can also be obtained from the metals which absorb this gas. Iron, which had been treated with hydrogen at high temperature, kindly supplied by Mr. P. P. Cioffi of the Bell Laboratories, gave strong spots of hydrogen. It was found that cerium metal served also as a strong source of hydrogen, singly charged ions of H_1 , H_2 and H_3 were all present. The metal evidently absorbs large quantity of hydrogen gas. But care must be taken not to drive off the absorbed gas by preliminary heating in the vacuum. It was found that a second photograph gave much weaker hydrogen spots than the first one. With both of these sources H_1 always appeared strongest.

To get strong positive rays from inert gases with the spark method is still somewhat of a problem. An attempt was made to get helium ions from radioactive minerals which presumably contain helium gas. It was found that cleveite ($\text{UO}_2 \cdot \text{UO}_3 \cdot \text{PbO} \cdot \text{ThO}_2$) gave a comparatively strong trace of helium at the first photograph, but a very weak one at the second.

The high frequency spark method has thus been shown to be able to give strong sources of multiply charged ions of almost all the elements.

The writer wishes to express his most sincere thanks to Professor A. J. Dempster who proposed this problem and has given constant guidance and inspiration throughout the investigation. He also wishes to thank Dr. A. E. Shaw for suggestions and help during the construction of the apparatus.



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